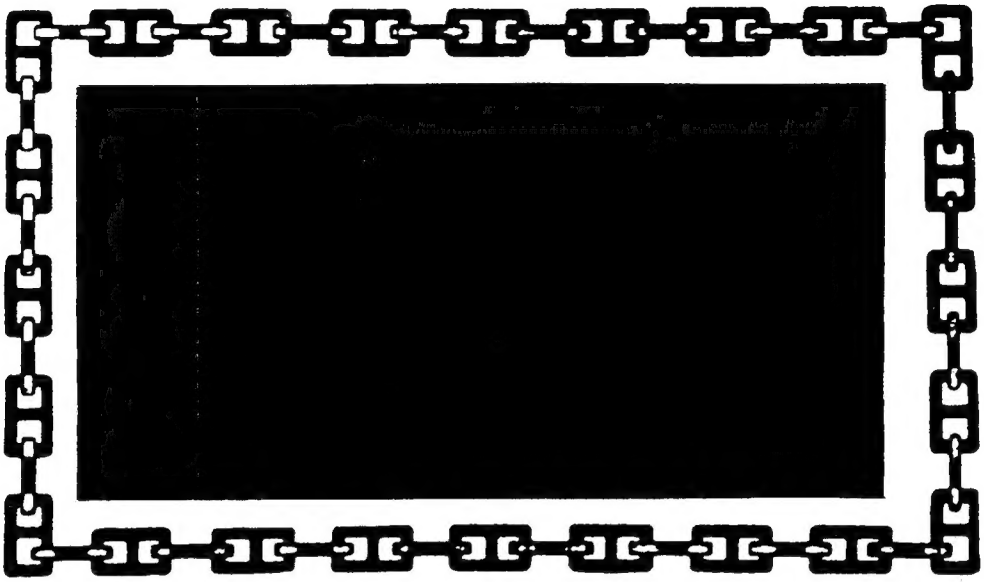

NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
321 BULLFINCH ROAD
PANAMA CITY, FLORIDA 32407-7015

IN REPLY REFER TO:

NAVSEA TASK 92-002 & 92-003

NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 12-94

EVALUATION OF MAKO 5436 HIGH PRESSURE BREATHING AIR COMPRESSOR

GEORGE D. SULLIVAN
April 1994

Approved for public release; distribution unlimited

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

In response to NAVSEA tasking, Navy Experimental Diving Unit (NEDU) evaluated the MAKO 5436 High Pressure Breathing Air Compressor from April 1994 to May 1994. This test was to determine if the compressor, when operating at 5000 PSI, met Navy diving community requirements. Based on the test results NEDU recommends that the compressor be placed on the Aopproved for Navy Use list published by NAVSEA OOC.

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ILLUSTRATIONS

I. INTRODUCTION

In response to NAVSEA tasking[1] a MAKO HIGH PRESSURE AIR COMPRESSOR, MODEL 5436, ELECTRIC DRIVE was tested[2] by Navy Experimental Diving Unit (NEDU). The unit was previously tested (NEDU Test No. 91-04) and approved by NAVSEA for inclusion in the ANU list[3] at an operating pressure of 211 bar (3000 psig). The purpose of this test was to re-evaluate the unit at 345 bar (5000 psig) and:

A. Determine if the compressor provides compressed air at the required pressures, flow rates, quality and cleanliness required by the U.S. Navy[4].

B. Determine the adequacy of the manufacturer's information, instructions and guidance for the safe operation and overall management of the compressor.

II. EQUIPMENT DESCRIPTION

A. GENERAL

The MAKO, MODEL 5436 high pressure, breathing air compressor (Figure 1) is of a four stage, four cylinder, single acting, "vee" configuration.

A forced lubrication system is utilized. Lubricating oil is supplied under pressure to the main bearings via a filter and crankshaft passages. Oil is forced through the bearing clearance and thrown off the rotating crankshaft to ensure an adequate supply to cylinders, pistons, and crossheads. The third and fourth stages are lubricated through a dedicated mechanical lubricator. Sight glasses allow observation of compressor sump oil level and the feed rate of the third and fourth stage mechanical lubricator. The mechanical lubricator tank is supplied by the compressor oil sump. The compressor requires approximately 45 liters (11.8 gallons) of lubricating oil, and the cylinder lubricator requires 1.0 liter (2.1 pint) of oil.

Compressor cooling is by water through a closed radiator type system. Water from this system is pumped through the jackets and passages of the compressor and returned to the radiator for heat removal.

The drive unit for this test was a 460 Volt, 3 Phase, 75 Horsepower, Reliance A/C motor. It is equipped with a slide motor plate and "V" belt pulley. Rotational torque is transferred to the compressor by five "V" belts. Electric motors purchased for use with this compressor shall comply with Navy standards for sealed insulation units[5].

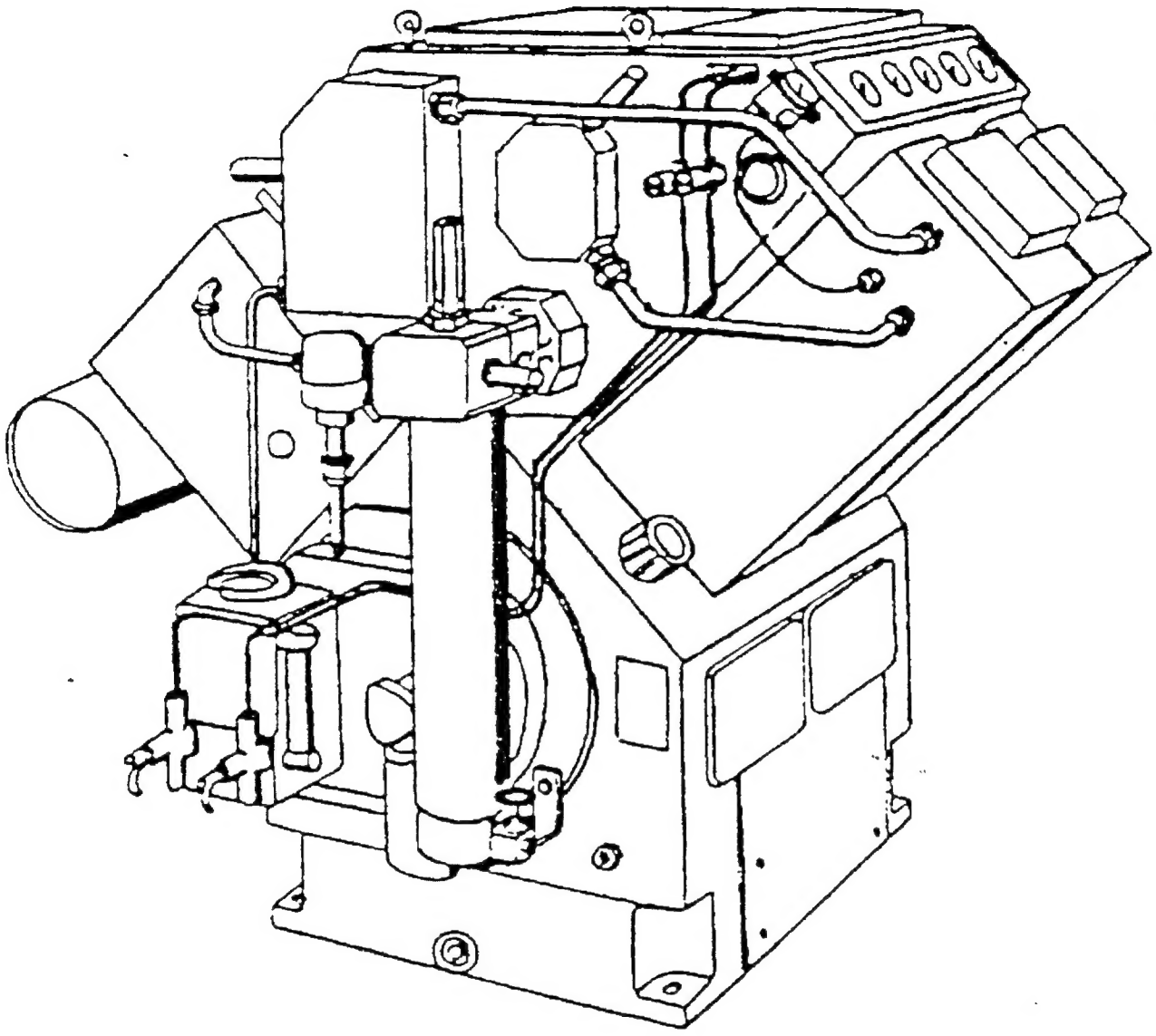

Figure 1 5436 High Pressure Air Compressor

The MAKO compressor unit consists of a compressor block, auto drain monitoring system, and a drive motor mounted on a steel frame secured to a concrete floor.

The compressor air system consists of an interstage separator, auto drain system, and auto drain reservoir. The interstage separators are installed between the 2nd and 3rd, and the 3rd and 4th stages. Internal operation of the interstage separators is through a nozzle which separates water and oil from the compressed air. The interfilter requires routine maintenance (periodic draining).

The auto drain system blows down the separators at 15 minute intervals. This is accomplished by an electric timer which deactivates a solenoid valve that controls the pressure on a bank of piston type valves isolating the separators from the reservoir. Residual oil and water vapors not drained by the auto-drain system are removed by a down stream filter purification system.

The MAKO 5436 compressor has a rated capacity of 2548 liters per minute (90 scfm) free air delivered at 345 bars (5,000 psi).

A pressure maintaining/non-return valve set at 145 bars (2,100 psi) is provided. This ensures that pressure build-up occurs during start up and initial compressor air delivery. This achieves constant, optimum moisture separation, fourth stage piston ring expansion/cylinder sealing, and prevents compressed air return from the storage flasks to the compressor during unit shut down. All four stages of the compressor are protected by safety relief valves.

The MAKO, MODEL 5436 comes with one Breathing Air Module Owner's Manual[5] which is divided into the following sections;

1. Leading Particulars
2. General Description
3. Installation
4. Commissioning or Recommissioning
5. Operation & Routine Maintenance
6. Valve Servicing
7. Fault Guide
8. Illustrated List of Parts

III. TEST PROCEDURE

There are various methods of testing compressor capacities, stability, and reliability. For this compressor evaluation[2], NEDU chose to continuously run the compressor for extended periods charging a 178.39 liter floodable volume (6.3 cuft) cylinder bank from 0 bars to 345 bars (0 to 5,000 psig).

The compressor was a permanently installed part of the NEDU EDF air system. A Cole Palmer Model 8502-14 temperature monitor and Yellow Springs Instruments 700 Series thermistor probes were attached for measuring compressor discharge and ambient temperatures. Figure 2 provides a diagram of the test equipment set up.

Appendix A shows the recorded data from the Test Log. The unit was operated in an interior work area, open to ambient temperature and humidity. The testing included subjective evaluation of the system operation but did not include detailed mechanical review of the individual components of the system.

The compressor was operated using one external final separator. No other purification systems were used. A total of 25 test hours were expended. The following parameters were recorded:

1. Date
2. Time
3. Meter Test Hours
4. Ambient Temperature
5. Compressor Air Discharge Temperature
6. Ambient Humidity
7. Cylinder Charging Time
8. Compressor Water Pressure
9. Compressor 3rd Stage Temperature
10. Compressor Oil Pressure
11. Compressor Stage Pressures
12. Final Discharge Pressure
13. Compressor free air capacity flow rate

Appendix A is recorded data from the Test Log.

IV. OBSERVATIONS/RECOMMENDATIONS

A. AIR DELIVERY

Compressor capacity was determined to be 2,763.66 liters per minute (97.6 cfm) by calculating the average time to charge a 178.39 liter (6.3 cuft) floodable volume cylinder from 0 to 345 bars (0 to 5,000 psig). Calculations are shown in Appendix A.

B. AIR SAMPLING

Air samples were taken from the compressor discharge at the 1 and 25 hour running time. The samples were sent to the Coastal Systems Station (CSS) Laboratory, Code 5130, for purity analysis. Analysis of air samples are listed in Appendix B.

C. OIL LUBRICATION

At the beginning of the test, the compressor oil sump level indicated full. Oil level was checked every 30 minutes using the oil level sight glass. Oil consumption was logged in Appendix A. During the 25 hours, a total of 0.94 liters (1 quart) of oil was added to the compressor. The oil used during the test was Anderol 750 compressor oil. MAKO Technical Manual[6] CAUTION states:

"The following synthetic oils are approved:

Reavellite
Anderol 500

The above oils have been found to give better and more consistent valve life on high pressure valves (i.e. third and fourth stages)."

D. MAINTENANCE

No factory maintenance was scheduled during this test.

E. PRIME MOVER

This task requested NEDU to test the compressor only. Commands procuring primemovers for these compressors must ensure that they meet Navy specifications. The prime mover, if electric, should be a sealed insulation system (service A use) in accordance with MIL-M-17060 E[6], Amendment 1.

F. CADMIUM FITTINGS

General Specifications[7] state that cadmium coated fittings cannot be used in systems that exceed 400 degrees Fahrenheit or if the cadmium could come in contact with petroleum products. At this time the only authorized HP compressor lubricant by the Navy is the petroleum based 2190 TEP (a petroleum based product). Recommend cadmium coated fittings be replaced with a suitable substitute.

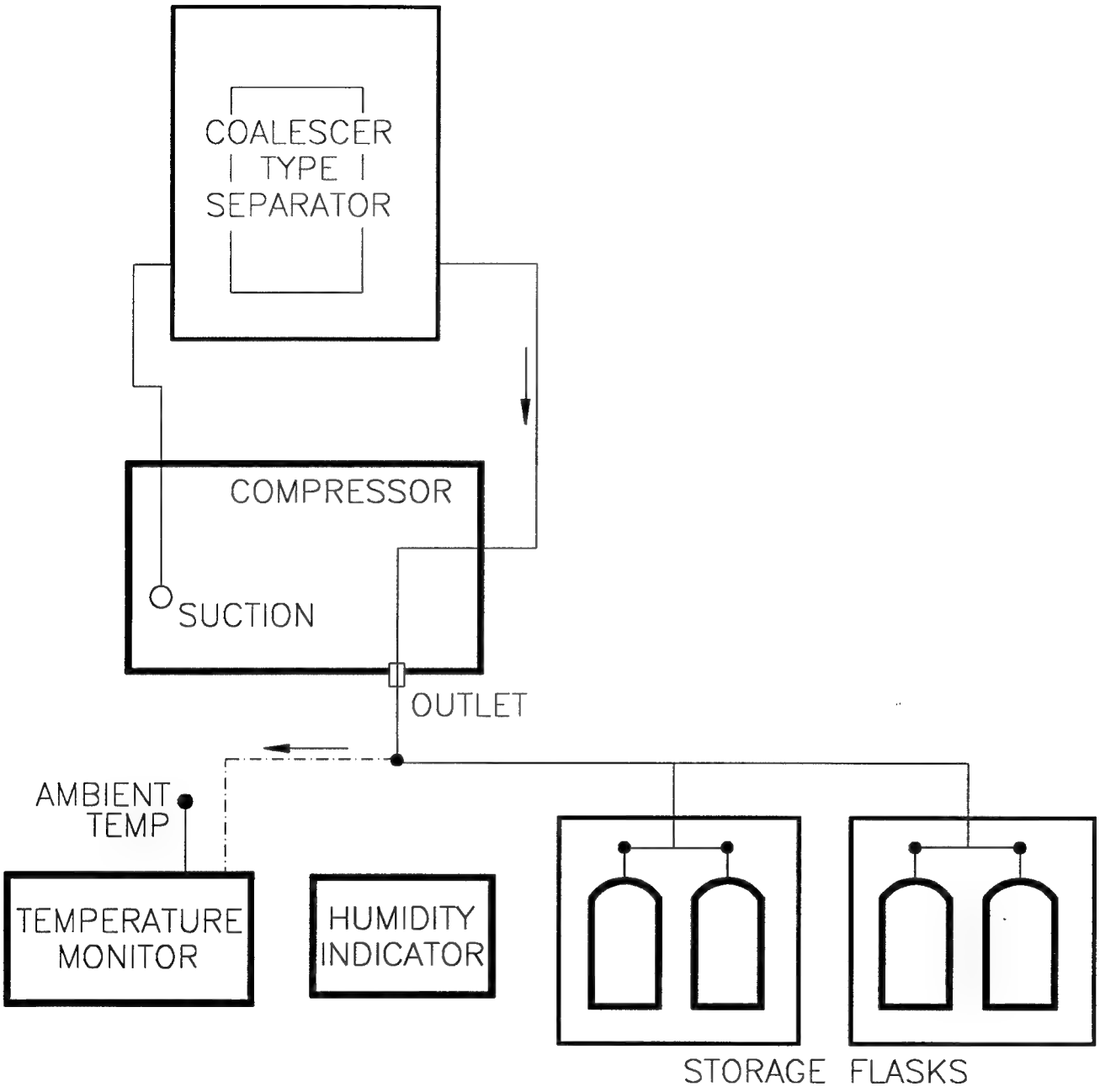

Figure 2 NEDU Test No. 93.35 Equipment Configuration

V. CONCLUSIONS

A. The high pressure air compressor delivers air which meets U.S. Navy standards[4] at an average rate of 2,763.66 liters per minute (97.6 cfm) per Appendix A. This meets the manufacturer's specification.

B. The unit is sturdy, reliable and readily maintained.

C. Based on the results of testing, the MAKO 5436 high pressure air compressor system is recommended for inclusion on the Authorized for Navy Use List[3].

D. The vendor and NAVSEA should be contacted prior to purchase to ensure the unit meets the user's needs.

VI. REFERENCES

1. NAVSEA Task 92-002; Evaluation of Commercially Available Divers Air Compressors

2. MAKO 5436 High Pressure Air Compressor Evaluation 5000 PSIG (Unmanned) Test Plan 93-35 (Limited Distribution), Navy Experimental Diving Unit, September 1993

3. NAVSEAINST 10560.2B Diving Equipment Authorized for U. S. Navy Use

4. NAVSEA 0994-LP-001-9010 U.S. Navy Diving Manual Volume 1, Rev. 3, Paras 5.3.2. Air purity standards, and 6.7.2.1. Air Compressors

5. Breathing Air Module (5436) Manual, Mako Compressors, Inc. 1634 SW 17 Street Ocala, Florida 34474

6 MIL-M-17060 E Amendment 1, Sealed Insulated Systems, (service A use). Navy specification for compressor power source

7. Navy Publication No. S9AA-AA-SPN-010/GENSPEC, General Specifications for Ships of the Navy, Cadmium Fittings, January 19, 1987

DATE: APRIL 29, 1994

TIME	METER HOURS	TEMP°F		AMBI HUMID %	CYL FILL TIME	CYLINDER CHARGING INFORMATION			CHARGED CYLINDER SIZE		WATER PRESS	COMP TEMP °F	OIL PRESS	COMPRESSOR CYLINDER STAGES PSI			
		AMBI TEMP°F	COMP DSCHG °F			START TIME	END TIME	END PSI	RATED CUFT	RATED PSI				1ST	2ND	3RD	4TH
0845	431.4	78	54	67	-	-	-	-	-	-	35	110	35	40	220	1050	2100
0900	431.6	78	96	65	-	-	-	-	-	-	35	135	33	44	250	1100	2350
0930	432.1	77	113	67	-	0950	-	-	-	-	35	158	35	44	260	1280	4100
1000	432.6	78	105	79	:22	-	1012	5000	6.3	5000	35	150	34	44	250	1090	2100
1030	433.1	80	109	79	-	-	-	-	-	-	35	145	33	44	250	1090	2100
1100	433.6	81	118	75	-	1110	-	-	-	-	35	150	33	44	250	1100	2200
1130	434.1	80	122	73	:22	-	1132	5000	6.3	5000	35	155	33	44	260	1200	3200
1200	434.6	82	99	70	-	-	-	-	-	-	35	140	33	44	250	1050	2100
1230	435.2	81	119	71	-	-	-	-	-	-	35	160	33	44	260	1150	3100
1300	435 6	82	119	73	-	-	-	-	-	-	35	165	33	44	260	1250	4000

0830 Checked oil levels
0845 Started compressor testing
1300 Secured compressor testing

The mean time for pressurizing an 178.39 liter (6.3cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.14 ATA is: $\frac{22 + 22}{2} = 22$ minutes. Therefore, the charging rate is: $\frac{178.39 \ X \ 341.14}{22} = 2766.21 \ LPM \ (97.6 CFM)$

DATE: MAY 2, 1994

TIME	METER HOURS	TEMP°F		AMBI HUMID %	CYL FILL TIME	CYLINDER CHARGING INFORMATION			CHARGED CYLINDER SIZE		WATER PRESS	COMP TEMP °F	OIL PRESS	COMPRESSOR CYLINDER STAGES PSI			
		AMBI TEMP°F	COMP DSCHG° F			START TIME	END TIME	END PSI	RATED CUFT	RATED PSI				1ST	2ND	3RD	4TH
0700	435.6	69	59	100	-	-	-	-	-	-	35	95	36	40	240	1050	2100
0725	436.0	70	103	95	-	0728	-	-	-	-	35	145	33	44	260	1300	4200
0800	436.5	70	96	91	:22	-	0750	5000	6.3	5000	35	145	35	44	250	1050	2100
0830	437.0	70	114	91	-	-	-	-	-	-	35	155	34	45	260	1300	4900
0900	437.5	70	101	91	-	-	-	-	-	-	35	140	34	44	250	1050	2100
0930	438.0	72	115	90	-	-	-	-	-	-	35	150	34	44	260	1200	3600
1000	438.5	73	118	86	-	-	-	-	-	-	35	160	34	44	260	1300	4800
1030	439.1	73	109	82	-	-	-	-	-	-	35	145	34	44	250	1100	2200
1100	439.5	73	117	81	-	-	-	-	-	-	35	165	33	44	260	1300	4100
1130	440.0	74	110	79	-	-	-	-	-	-	35	150	33	44	250	1050	2100
1200	440.5	76	117	82	:22	1202	1224	5000	6.3	5000	35	165	33	44	260	1250	4000
1230	441.0	76	113	81	-	-	-	-	-	-	35	155	33	44	250	1050	2100
1300	441.5	76	118	80	-	-	-	-	-	-	35	160	33	44	260	1200	3200
1330	442.0	78	110	78	-	-	-	-	-	-	35	150	33	44	250	1100	2200
1400	442.5	79	114	73	-	-	-	-	-	-	35	155	33	44	250	1100	2100
1430	443.0	80	121	76	-	-	-	-	-	-	35	170	32	44	260	1300	5000

0645 Checked compressor oil level
0700 Started compressor testing
1445 Secured compressor testing

The mean time for pressurizing an 178.39 liter (6.3cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.14 ATA is: $\frac{22 + 22}{2} = 22$ minutes. Therefore, the charging rate is: $\frac{178.39 \times 341.14}{22} = 2766.21$ *LPM* (97.6*CFM*)

DATE MAY 3, 1994

TIME	METER HOURS	TEMP°F		AMBI HUMID %	CYL FILL TIME	CYLINDER CHARGING INFORMATION			CHARGED CYLINDER SIZE		WATER PRESS	COMP TEMP °F	OIL PRESS	COMPRESSOR CYLINDER STAGES PSI			
		AMBI TEMP°F	COMP DSCHG°F			START TIME	END TIME	END PSI	RATED CUFT	RATED PSI				1ST	2ND	3RD	4TH
0700	443.3	73	53	90	-	-	-	-	-	-	35	100	37	40	240	1050	2100
0730	443.8	73	107	92	-	-	-	-	-	-	35	155	35	44	260	1200	3200
0800	444.4	73	99	94	-	0816	-	5000	6.3	5000	35	140	34	43	250	1050	2100
0830	444.9	76	109	72	:22	-	0838	-	-	-	35	150	34	43	250	1150	2300
0900	445.3	76	117	85	-	-	-	-	-	-	35	160	34	44	260	1300	4400
0930	445.9	77	114	86	-	-	-	-	-	-	35	140	33	43	250	1150	3000
1000	446.4	78	108	80	-	-	-	-	-	-	35	150	33	43	250	1100	2150
1030	446.9	79	116	81	-	-	-	-	-	-	35	160	33	43	260	1200	3200
1100	447.4	79	110	83	-	-	-	-	-	-	35	150	33	43	250	1100	2200
1130	447.9	78	112	81	-	-	-	-	-	-	35	145	33	44	250	1100	2300
1200	448.4	78	104	87	-	-	-	-	-	-	35	150	33	44	250	1050	2100
1230	448.9	78	119	89	-	-	-	-	-	-	35	170	33	44	260	1300	4800
1300	449.4	78	116	89	-	-	-	-	-	-	35	150	33	44	250	1150	3000
1330	449.9	78	95	87	-	-	-	-	-	-	35	145	33	44	250	1050	2100
1400	450.4	78	117	89	-	-	-	-	-	-	35	160	33	44	260	1250	4200
1430	450.9	78	107	90	-	-	-	-	-	-	35	150	33	44	250	1050	2100
1450	451.2	SECURED	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

0650 Checked compressor oil level
0655 Started compressor testing
1450 Secured compressor testing

The mean time for pressurizing an 178.39 liter (6.3cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.14 ATA is: 22 minutes. Therefore, the charging rate is: $\frac{178.39 \; X \; 341.14}{22} = 2766.21 \; LPM \; (97.6 CFM)$

DATE: MAY 4, 1994

TIME	METER HOURS	TEMP°F		AMBI HUMID %	CYL FILL TIME	CYLINDER CHARGING INFORMATION			CHARGED CYLINDER SIZE		WATER PRESS	COMP TEMP °F	OIL PRESS	COMPRESSOR CYLINDER STAGES PSI			
		AMBI TEMP°F	COMP DSCHG°F			START TIME	END TIME	END PSI	RATED CUFT	RATED PSI				1ST	2ND	3RD	4TH
0650	451.2	71	51	88	-	-	-	-	-	-	35	110	35	40	240	1050	2100
0700	451.4	73	66	89	-	-	-	-	-	-	35	135	33	42	240	1050	2100
0730	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0830	452.0	75	105	73	-	-	-	-	-	-	35	155	35	44	260	1200	3600
0900	452.4	79	100	52	-	-	-	-	-	-	35	145	35	44	250	1050	2100
0930	452.9	79	117	57	-	0936	-	-	-	-	35	170	33	44	260	1300	4900
1000	453.4	80	105	63	:22	-	0958	5,000	6.3	5,000	35	160	33	44	250	1050	2100
1030	453.9	79	118	70	-	-	-	-	-	-	35	170	33	44	260	1250	3800
1100	454.4	80	109	68	-	-	-	-	-	-	35	155	33	44	250	1050	2100
1130	454.9	81	123	65	-	-	-	-	-	-	35	175	33	44	260	1300	4600
1200	455.4	82	121	68	-	-	-	-	-	-	35	170	33	44	260	1250	3800
1230	456.0	81	117	68	-	-	-	-	-	-	35	160	33	44	250	1150	2600
1300	456.4	81	119	67	-	-	-	-	-	-	35	165	33	44	260	1200	3200

0645 Checked compressor oil level
0650 Started compressor testing
0710 Secured due to back-pressure regulator failure
0817 Started compressor testing (repaired back-pressure regulator
1300 Secured compressor testing (25 hours)
1305 Added 0.94 liters (1 quart) Anderol 750 oil to refill compressor

The mean time for pressurizing an 178.39 liter (6.3cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.14 ATA is: 22 minutes. Therefore, the charging rate is: $\frac{178.39 \times 341.14}{22} = 2766.21$ *LPM* (97.6*CFM*)

Memorandum

29 April 1994

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample marked MAKO 5430 Evaluation Test # 93-35 1 hour Sample.

In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21.0%	20-22%[2]
Nitrogen	78.1%	NONE[2]
Argon	0.9%	NONE[2]
Carbon Dioxide	335 PPM	1000 PPM[2]
Total Hydrocarbons[1]	1.6 PPM	25 PPM[2]
Carbon Monoxide	1.6 PPM	20 PPM[2]
Methane	1.6 PPM	1000 PPM[2]
Acetone	<0.1 PPM	200 PPM[2]
Benzene	<0.1 PPM	1 PPM[2]
Chloroform	<0.1 PPM	1 PPM[2]
Ethanol	<0.1 PPM	100 PPM[2]
Freon 113	<0.1 PPM	100 PPM[2]
Freon 11	<0.1 PPM	100 PPM[2]
Freon 12	<0.1 PPM	100 PPM[2]
Freon 114	<0.1 PPM	100 PPM[2]
Isopropyl Alcohol	<0.1 PPM	1 PPM[2]
Methanol	<0.1 PPM	10 PPM[2]
Methyl Chloroform	<0.1 PPM	30 PPM[2]
Methyl Ethyl Ketone	<0.1 PPM	20 PPM[2]
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM[2]
Methylene Chloride	<0.1 PPM	25 PPM[2]
Toluene	<0.1 PPM	20 PPM[2]
Trimethyl Benzenes	<0.1 PPM	3 PPM[2]
Xylenes	<0.1 PPM	50 PPM[2]

Other Components

Component	Level	Limit
NONE		
C4+	<0.1 PPM	NONE

[1]Expressed as methane equivalents.
[2]Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
[3]OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason
Chemist

Memorandum

06 MAY 1994

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample marked MAKO 5436 Evaluation Test # 93-35, 25 hour Sample.

In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21.0%	20-22%[2]
Nitrogen	78.1%	NONE[2]
Argon	0.9%	NONE[2]
Carbon Dioxide	322 PPM	1000 PPM[2]
Total Hydrocarbons[1]	1.7 PPM	25 PPM[2]
Carbon Monoxide	2.4 PPM	20 PPM[2]
Methane	1.7 PPM	1000 PPM[2]
Acetone	<0.1 PPM	200 PPM[2]
Benzene	<0.1 PPM	1 PPM[2]
Chloroform	<0.1 PPM	1 PPM[2]
Ethanol	<0.1 PPM	100 PPM[2]
Freon 113	<0.1 PPM	100 PPM[2]
Freon 11	<0.1 PPM	100 PPM[2]
Freon 12	<0.1 PPM	100 PPM[2]
Freon 114	<0.1 PPM	100 PPM[2]
Isopropyl Alcohol	<0.1 PPM	1 PPM[2]
Methanol	<0.1 PPM	10 PPM[2]
Methyl Chloroform	<0.1 PPM	30 PPM[2]
Methyl Ethyl Ketone	<0.1 PPM	20 PPM[2]
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM[2]
Methylene Chloride	<0.1 PPM	25 PPM[2]
Toluene	<0.1 PPM	20 PPM[2]
Trimethyl Benzenes	<0.1 PPM	3 PPM[2]
Xylenes	<0.1 PPM	50 PPM[2]

Other Components

Component	Level	Limit
NONE		
C4+	<0.1 PPM	NONE

[1]Expressed as methane equivalents.
[2]Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
[3]OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason
Chemist